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# Quality Characteristics of Aerobically Packaged and Irradiated Normal, PSE, and DFD Pork

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**Abstract**
Irradiation and storage increased lipid oxidation of normal and pale-soft-exudative (PSE) muscles, whereas dark-firm-dry (DFD) muscle was very stable and resistant to oxidative changes. Irradiation increased redness regardless of pork-quality type, and the increases were proportional to irradiation dose. Irradiation increased the production of sulfurcontaining volatiles, but not lipid oxidation products. The total volatiles produced in normal and PSE pork were higher than that in the DFD pork. Some volatiles produced in meat by irradiation evaporated during storage under aerobic packaging conditions. Nonirradiated normal and DFD pork had higher odor preference scores than the nonirradiated PSE, but irradiation reduced the preference scores of all three pork-quality types. This suggests that irradiation can significantly increase the use of DFD pork, and can greatly benefit pork and beef industries.

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# Quality Characteristics of Aerobically Packaged and Irradiated Normal, PSE, and DFD Pork

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### Summary and Implications

Irradiation and storage increased lipid oxidation of normal and pale-soft-exudative (PSE) muscles, whereas dark-firm-dry (DFD) muscle was very stable and resistant to oxidative changes. Irradiation increased redness regardless of pork-quality type, and the increases were proportional to irradiation dose. Irradiation increased the production of sulfur-containing volatiles, but not lipid oxidation products. The total volatiles produced in normal and PSE pork were higher than that in the DFD pork. Some volatiles produced in meat by irradiation evaporated during storage under aerobic packaging conditions. Nonirradiated normal and DFD pork had higher odor preference scores than the nonirradiated PSE, but irradiation reduced the preference scores of all three pork-quality types. This suggests that irradiation can significantly increase the use of DFD pork, and can greatly benefit pork and beef industries.


### Introduction

The objective of this study was to determine and compare the effects of irradiation on lipid oxidation, off-odor volatiles, color, and sensory characteristics of aerobically packaged normal, PSE, and DFD pork.

### Materials and Methods

*Sample preparation:* Twenty-four pork loin (*Longissimus dorsi*) muscles, eight each of normal (pH 5.7-5.8), PSE (pH 5.4 or less), and DFD (pH 6.2-6.8) meat, were purchased from a local packing plant. The pork loins were trimmed of all fat from the surface, and the lean muscle was sliced to 3-cm-thick steaks and packaged in polyethylene oxygen-permeable bags. After packaging, they were stored overnight at 4°C and then irradiated using a linear accelerator. The target doses of irradiation were 0, 2.5, and 4.5 kGy. The pork steaks were stored at 4°C for up to 10 days. The pH of meat samples was measured after 0, 5, and 10 days of storage after homogenizing samples with 9 volumes of deionized distilled water. Color and lipid oxidation in aerobically packaged irradiated pork loins were determined at 0, 5, and 10 days; volatile production at 0 and 10 days; and sensory analysis at 7 days of storage.

*TBARS value:* The fluorometric TBARS method was used to determine the extent of lipid oxidation in raw meat.

*Volatiles compound analysis:* A purge-and-trap apparatus connected to a gas chromatograph/mass spectrometry was used to analyze the volatiles responsible for the off-odor in samples. Identification of volatiles was achieved by comparing mass spectral data of samples with those of the Wiley library and standards when available. The area of each peak was integrated using the ChemStation software, and the total peak area (pA x sec) x $10^4$ was reported as an indicator of volatiles generated from the meat samples. The peaks produced by mass spectral data were grouped into five major volatile classes - ketones, alcohols, aldehydes, sulfur (S)-containing compounds and hydrocarbons - and reported.

*Sensory analysis:* The intensity of odor and preference for the odor of meat samples were determined at 7 days of storage using 76 sensory panelists. For evaluation of odor, samples containing 3-g muscle in coded, capped glass scintillation vials were presented to each panelist in isolated booths. A 15-cm linear hedonic scale, anchored at opposite ends with the words ‘no irradiation odor’ and ‘very strong irradiation odor’, and ‘not preferable’ and ‘highly preferable’, was used to rate the samples on the intensity of irradiation odor and on the preference for the irradiation odor. The responses from the panelists were expressed in numerical values ranging from 0 (no irradiation odor or not preferable) to 15 (strong irradiation odor or highly preferable) to the nearest 0.1 cm.

### Results and Discussion

*PH:* The pH values for the nonirradiated and irradiated normal, PSE, and DFD pork (Table 1) showed that irradiation had no effect on the pH of all three quality types of pork *L. dorsi* muscle with aerobic packaging. The original ultimate pH of normal, PSE, and DFD meat has been maintained throughout the 10-day storage.

*Color:* The most important factor influencing L-values was meat type. PSE pork, which has low pH, had the highest L-value, whereas DFD pork had the lowest L-value among the three meat types. Irradiated pork loin had greater a-values than nonirradiated pork chops regardless of meat type, and the increase in a-values was proportional to irradiation dose (Table 2). Furthermore, the redness was not decreased during the 10-day storage period even in aerobic packaging conditions. Although there have been several inconsistent results in terms of the stability of increased redness in irradiated meat, the red/pink pigment formed by irradiation in this experiment was not easily oxidized. Therefore, irradiation could have a desirable effect on improving the color of PSE pork, which has a detrimental pale color and reduced pigment stability. The b-values of PSE loin meats were higher than the normal and DFD samples at day 0 of storage. Color b-value increased during storage in all three pork types, but yellowness usually does not have much impact on the overall color of meat. Irradiation had no effect on the b-values of pork loin.

*TBARS values:* Meat type, irradiation, and storage time all influenced lipid oxidation of aerobic-packaged pork loin (Table 3). Irradiation and storage time increased the TBARS values of normal and PSE loin muscles, whereas DFD loin was not influence by irradiation. DFD loin was very stable and resistant to the quality changes by irradiation and storage. DFD meat has high water holding capacity and intact membrane structure, which can act as a barrier against the attack of free radicals such as hydroxyl radicals. Therefore, irradiation could be more useful for DFD meat than the normal and PSE meat. Because DFD meat is more susceptible to bacterial spoilage than other pork types, its use as a meat ingredient or for retail cuts is highly limited. However, if combined with irradiation, DFD meat could be an excellent meat source for further processing or for retail cuts.

PSE pork was more susceptible to lipid oxidation than the normal and DFD pork when irradiated and stored under aerobic conditions (Table 3). Cooked meat is highly susceptible to lipid oxidation because the cooking process denatures antioxidant components, damages cell structure, and exposes membrane lipids to the environment. As in cooked meat, the membrane structure of PSE pork would be leaky because of protein denaturation by low pH and high carcass temperature at early postmortem. Through the holes generated by denatured membrane proteins, water molecules can easily get into membrane bilayers. Along with the water, free ionic iron and iron proteins confined inside of cells under normal conditions may also get into membrane bilayers and promote oxidative reactions when free radicals are available. Hydroxyl radicals can be formed from water molecules in all meat conditions upon irradiation, and the reaction of hydroxyl radicals is site specific because of their short half-life ($10^{-6}$ sec). Therefore, the distribution of water and its location are critical for the irradiation-dependent initiation of lipid oxidation.

*Volatile compounds:* Meat type as well as storage time affected the production and the composition of volatiles in aerobically packaged pork loins (Table 4). At day 0 of storage, nonirradiated normal pork loins produced the higher amount of ketones than the PSE and DFD pork, but PSE pork produced the higher amount of alcohols and total volatiles than the normal and DFD porks. The amounts of ketones and alcohols in meat decreased significantly after irradiation. The production of sulfur-containing volatile compounds in pork increased by irradiation, but no difference in S-compounds between 2.5 and 4.5 kGy was observed. DFD pork produced the least amount of S-containing volatiles among the three meat types at each irradiated and nonirradiated conditions (Table 4). The pH of the meat system could have an important role in producing S-containing volatile compounds by irradiation. The major S-containing volatile compounds found in irradiated pork include mercaptomethane, dimethyl sulfide, carbon disulfide, methyl thioacetate, and dimethyl disulfide. Patterson and Stevenson (2) found that dimethyltrisulfide is the most potent off-odor compound, and the changes that occur after irradiation are distinctively different from those of the warmed-over flavor in oxidized meat. Ahn et al. (1) reported that S-containing volatiles such as 2,3-dimethyl disulfide produced by radiolytic amino acids were responsible for the off-odor in irradiated pork. They also assumed that the off-odor volatiles in irradiated pork were the result of compounding effects of volatiles from lipid oxidation and other reactions such as radiolysis of amino acid side chains. The production of aldehydes and hydrocarbons in pork were also influenced by irradiation, but their changes by irradiation were not as severe as those of other volatile groups.

As storage time increased, the composition of volatiles in pork changed significantly. A large amounts of ketones from nonirradiated normal and alcohols from nonirradiated PSE pork after 10 days of storage in aerobic-packaging conditions. After 10 days of storage, the amounts of most volatile groups (except for ketones) decreased from those at day 0, and the differences in irradiation effect by meat type decreased. In particular, the amounts of S-containing volatiles in irradiated samples decreased drastically, and their differences among meat types also disappeared except for the DFD samples irradiated at 2.5 kGy. This result indicated that the volatiles produced by irradiation were escaped during storage under aerobic-packaging conditions. The disappearance rate of S-containing volatile compounds of irradiated DFD pork was slower than that of the normal or PSE pork.

*Sensory characteristics:* Meat type and irradiation dose affected ($P < 0.05$) the intensity of irradiation odor and the preference for a meat odor (Table 5). The off-odor intensity of PSE was higher than normal and DFD meat in nonirradiated samples. Irradiation increased the intensity of irradiation odor, which was not significantly different among irradiated normal, PSE, and DFD meat. The preference for a meat odor also was consistent with the result of intensity of irradiant odor. As the irradiation odor in meat became more intense, the preference for the meat odor decreased because most trained panelists considered irradiation odor as an off-odor.

In nonirradiated samples, the preference for a meat odor for normal and DFD meat was higher than the PSE meat. After irradiation, however, there was no difference in odor preference for the three pork types. Ahn et al. (1) reported that sensory characteristics of irradiated meat were described as having a barbecued cornlike odor, and sensory panels showed no objection to the odor. However, irradiation of pork at the 2.5 kGy level decreased the odor preference for all three pork types in this study.

## Conclusion

Irradiation increased TBARS and off-odor in aerobically packaged pork. But DFD pork, which usually is underutilized because of its microbial susceptibility, was more stable and resistant to lipid oxidation and off-odor production by irradiation than the normal pork.

## References

1. Ahn, D.U., Jo, C., and Olson, D.G. (2000). Analysis of volatile components and the sensory characteristics of irradiated raw pork. Meat Sci. 54:209-215.
2. Patterson, R.L.S. and Stevenson, M.H. (1995). Irradiation-induced off-odor in chicken and its possible control. Br. Poult. Sci. 36:425-441.

**Table 1. The pH of aerobically packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose and storage time at 4°C.**

| Storage | 0 kGy | | | 2.5 kGy | | | 4.5 kGy | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| time | Norm | PSE | DFD | Norm | PSE | DFD | Norm | PSE | DFD | SEM |
| Day 0 | 5.69$^{b}$ | 5.47$^{c}$ | 6.39$^{a}$ | 5.64$^{b}$ | 5.46$^{c}$ | 6.35$^{a}$ | 5.67$^{b}$ | 5.50$^{c}$ | 6.32$^{a}$ | 0.04 |
| Day 5 | 5.63$^{b}$ | 5.46$^{bc}$ | 6.42$^{a}$ | 5.60$^{b}$ | 5.40$^{c}$ | 6.42$^{a}$ | 5.66$^{b}$ | 5.46$^{bc}$ | 6.30$^{a}$ | 0.05 |
| Day 10 | 5.64$^{b}$ | 5.45$^{cd}$ | 6.53$^{a}$ | 5.59$^{bc}$ | 5.40$^{d}$ | 6.47$^{a}$ | 5.58$^{bc}$ | 5.49$^{bcd}$ | 6.40$^{a}$ | 0.04 |
| SEM | 0.04 | 0.04 | 0.06 | 0.03 | 0.03 | 0.06 | 0.04 | 0.02 | 0.05 | |

$^{a\text{-}d}$Different letters within a row are different ($P < 0.05$), N = 8.
[1]SEM: Standard errors of the mean among different meat type * irradiation within a storage time.
[2]SEM: Standard errors of the mean among different storage time within a meat type.

**Table 2. Color L-, a-, and b-values of aerobically packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose and storage time at 4°C.**

| Storage | 0 kGy | | | 2.5 kGy | | | 4.5 kGy | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| time | Norm | PSE | DFD | Norm | PSE | DFD | Norm | PSE | DFD | SEM |
| ***L-value*** | | | | | | | | | | |
| Day 0 | 48.1$^{by}$ | 54.9$^{a}$ | 42.3$^{c}$ | 49.5$^{b}$ | 56.7$^{a}$ | 37.0$^{dy}$ | 47.5$^{b}$ | 54.9$^{a}$ | 42.2$^{c}$ | 1.1 |
| Day 5 | 51.3$^{bcx}$ | 53.5$^{ab}$ | 41.9$^{d}$ | 52.1$^{b}$ | 55.9$^{bc}$ | 43.1$^{ax}$ | 49.5$^{c}$ | 52.8$^{abc}$ | 42.2$^{d}$ | 0.9 |
| Day 10 | 48.9$^{cy}$ | 51.9$^{bc}$ | 44.8$^{d}$ | 51.7$^{bc}$ | 58.1$^{a}$ | 44.6$^{dx}$ | 50.2$^{bc}$ | 53.1$^{b}$ | 42.1$^{d}$ | 1.1 |
| SEM | 0.8 | 0.9 | 1.1 | 1.0 | 1.0 | 1.4 | 1.0 | 1.0 | 0.9 | |
| ***a-value*** | | | | | | | | | | |
| Day 0 | 7.1$^{dey}$ | 6.6$^{ey}$ | 7.0$^{dey}$ | 8.6$^{cdy}$ | 8.9$^{cdx}$ | 10.5$^{bcx}$ | 13.2$^{ax}$ | 11.9$^{abx}$ | 12.5$^{ax}$ | 0.5 |
| Day 5 | 9.1$^{ay}$ | 7.8$^{abcxy}$ | 5.6$^{dy}$ | 7.9$^{abcy}$ | 6.5$^{cdz}$ | 7.0$^{bcy}$ | 8.9$^{az}$ | 7.3$^{bcz}$ | 8.5$^{aby}$ | 0.4 |
| Day 10 | 9.8$^{abcx}$ | 9.1$^{bcx}$ | 9.1$^{bcx}$ | 10.3$^{abx}$ | 7.8$^{cy}$ | 12.0$^{ax}$ | 11.1$^{aby}$ | 9.5$^{bcy}$ | 11.8$^{ax}$ | 0.6 |
| SEM | 0.4 | 0.5 | 0.5 | 0.3 | 0.2 | 0.7 | 0.6 | 0.5 | 0.7 | |
| ***b-value*** | | | | | | | | | | |
| Day 0 | 11.0$^{by}$ | 12.7$^{az}$ | 9.5$^{cdy}$ | 10.9$^{bz}$ | 12.7$^{ay}$ | 8.6$^{dy}$ | 11.0$^{bz}$ | 12.6$^{az}$ | 10.2$^{bcy}$ | 0.4 |
| Day 5 | 13.2$^{abx}$ | 13.8$^{ay}$ | 9.8$^{cy}$ | 13.4$^{aby}$ | 14.1$^{ax}$ | 10.0$^{cy}$ | 12.5$^{by}$ | 13.6$^{aby}$ | 9.8$^{cy}$ | 0.3 |
| Day 10 | 13.6$^{abx}$ | 14.6$^{ax}$ | 11.8$^{cx}$ | 14.4$^{ax}$ | 14.9$^{ax}$ | 12.6$^{bcx}$ | 14.4$^{ax}$ | 14.6$^{ax}$ | 11.7$^{cx}$ | 0.4 |
| SEM | 0.2 | 0.2 | 0.5 | 0.2 | 0.3 | 0.5 | 0.3 | 0.3 | 0.3 | |

$^{a\text{-}e}$Different letters within a row are significantly different ($P < 0.05$), N = 8.
$^{x\text{-}z}$Different letters within a column of same color value are significantly different ($P < 0.05$).

**Table 3. TBARS values of aerobically packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose and storage time at 4°C.**

| Storage | 0 kGy | | | 2.5 kGy | | | 4.5 kGy | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| time | Norm | PSE | DFD | Norm | PSE | DFD | Norm | PSE | DFD | SEM |
| | mg MDA/kg meat | | | | | | | | | |
| Day 0 | 0.10$^{cy}$ | 0.10$^{cy}$ | 0.10$^{c}$ | 0.10$^{cy}$ | 0.12$^{aby}$ | 0.10$^{c}$ | 0.13$^{ay}$ | 0.13$^{aby}$ | 0.10$^{cy}$ | 0.01 |
| Day 5 | 0.24$^{bx}$ | 0.20$^{bxy}$ | 0.09$^{c}$ | 0.32$^{ax}$ | 0.26$^{aby}$ | 0.11$^{c}$ | 0.28$^{abxy}$ | 0.28$^{abxy}$ | 0.12$^{cx}$ | 0.04 |
| Day 10 | 0.25$^{bx}$ | 0.23$^{bx}$ | 0.09$^{b}$ | 0.35$^{abx}$ | 0.64$^{ax}$ | 0.11$^{b}$ | 0.38$^{abx}$ | 0.47$^{abx}$ | 0.12$^{bx}$ | 0.09 |
| SEM | 0.04 | 0.03 | 0.01 | 0.06 | 0.10 | 0.01 | 0.07 | 0.07 | 0.01 | |

$^{a\text{-}c}$Different letters within a row are significantly different ($P < 0.05$), N = 8.
$^{x\text{-}y}$Different letters within a column are significantly different ($P < 0.05$).

**Table 4. Relative production of volatiles in aerobically packaged normal, PSE, and DFD pork *L. dorsi* muscle affected by irradiation dose at different storage times at 4°C.**

| Storage time | 0 kGy Norm | 0 kGy PSE | 0 kGy DFD | 2.5 kGy Norm | 2.5 kGy PSE | 2.5 kGy DFD | 4.5 kGy Norm | 4.5 kGy PSE | 4.5 kGy DFD | SEM |
|---|---|---|---|---|---|---|---|---|---|---|
| | Peak area (pA*sec) x $10^4$ | | | | | | | | | |
| ***Day 0*** | | | | | | | | | | |
| Ketones | $15867^{a}$ | $550^{c}$ | $3041^{c}$ | $761^{c}$ | $195^{c}$ | $335^{c}$ | $5308^{b}$ | $189^{c}$ | $218^{c}$ | 733 |
| Alcohols | $2402^{b}$ | $26350^{a}$ | $4014^{b}$ | $160^{b}$ | $1192^{b}$ | $0^{b}$ | $420^{b}$ | $370^{b}$ | $52^{b}$ | 86 |
| Aldehydes | $1055^{bc}$ | $763^{bc}$ | $1863^{a}$ | $472^{bc}$ | $844^{bc}$ | $684^{bc}$ | $633^{bc}$ | $1161^{b}$ | $399^{c}$ | 156 |
| S-compounds | $185^{d}$ | $1738^{c}$ | $65^{d}$ | $10037^{a}$ | $4643^{b}$ | $1274^{c}$ | $5143^{b}$ | $2979^{bc}$ | $2684^{c}$ | 592 |
| Hydrocarbons | $2167^{c}$ | $2066^{cd}$ | $1991^{cd}$ | $3918^{a}$ | $2403^{bc}$ | $1049^{e}$ | $3174^{ab}$ | $3112^{ab}$ | $1183^{de}$ | 253 |
| Total volatiles | $23145^{b}$ | $32796^{a}$ | $11639^{cd}$ | $16905^{c}$ | $9830^{d}$ | $3727^{d}$ | $16125^{c}$ | $7379^{d}$ | $4937^{d}$ | 1944 |
| ***Day 10*** | | | | | | | | | | |
| Ketones | $6040^{b}$ | $196^{c}$ | $3517^{bc}$ | $4357^{bc}$ | $0^{c}$ | $5718^{b}$ | $13128^{a}$ | $536^{c}$ | $1562^{bc}$ | 1248 |
| Alcohols | $127^{c}$ | $7664^{a}$ | $3067^{bc}$ | $165^{c}$ | $4913^{b}$ | $1199^{c}$ | $238^{c}$ | $1608^{c}$ | $131^{c}$ | 879 |
| Aldehydes | $276^{c}$ | $388^{ab}$ | $470^{ab}$ | $239^{c}$ | $845^{a}$ | $445^{ab}$ | $390^{ab}$ | $781^{ab}$ | $341^{bc}$ | 1 06 |
| S-compounds | $139^{d}$ | $182^{d}$ | $112^{d}$ | $267^{d}$ | $632^{c}$ | $2146^{a}$ | $448^{c}$ | $387^{c}$ | $1169^{b}$ | 94 |
| Hydrocarbons | $1305^{c}$ | $1679^{c}$ | $1291^{c}$ | $1713^{c}$ | $5203^{a}$ | $1395^{c}$ | $1959^{c}$ | $3031^{b}$ | $1768^{c}$ | 294 |
| Total volatiles | $8411^{b}$ | $10579^{ab}$ | $9294^{ab}$ | $7124^{b}$ | $12391^{ab}$ | $12519^{ab}$ | $16853^{a}$ | $7070^{b}$ | $6128^{b}$ | 1853 |

a-eDifferent letters within a row are significantly different ($P < 0.05$), N = 4

**Table 5. Sensory characteristics of aerobically packaged irradiated normal, PSE, and DFD pork *L. dorsi* muscle refrigerated for 7 days.**

| Irradiation | Norm | PSE | DFD | SEM |
|---|---|---|---|---|
| ***Irradiation odor intensity***[3] | | | | |
| 0 kGy | $2.90^{by}$ | $4.00^{ay}$ | $3.12^{by}$ | 0.26 |
| 2.5 kGy | $6.91^{x}$ | $6.72^{x}$ | $6.47^{x}$ | 0.35 |
| 4.5 kGy | $7.33^{x}$ | $7.32^{x}$ | $6.79^{x}$ | 0.36 |
| SEM | 0.32 | 0.34 | 0.32 | |
| ***Preference for the meat odor***[4] | | | | |
| 0 kGy | $9.12^{ax}$ | $8.14^{bx}$ | $9.36^{ax}$ | 0.33 |
| 2.5 kGy | $7.12^{y}$ | $6.75^{y}$ | $7.44^{y}$ | 0.31 |
| 4.5 kGy | $6.37^{y}$ | $6.56^{y}$ | $7.06^{y}$ | 0.35 |
| SEM | 0.33 | 0.33 | 0.34 | |

$^{a\text{-}b}$Different letters within a row are significantly different ($P < 0.05$, N = 76.
$^{x\text{-}y}$Different letters within a column of the same question are significantly different ($P < 0.05$).
[3]Irradiation odor intensity: 0, no irradiation odor; 15, very strong irradiation odor.
[4]Preference for the meat odor: 0, not preferable; 15, highly preferable.